From lab to life: Associating brain reward processing with daily life motivated behaviour and symptoms of depression in non-help-seeking young adults.

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Supplemental Materials

Group abbreviations:
m/m-D=participants with mild/moderate symptoms of depression; n/l-D=participants with no/low symptoms of depression.

fMRI data acquisition specifications.
Functional images were collected using a T2*-sensitive gradient echo sequence with 47 interleaved axial slices (S>>I) with a thickness of 3mm (voxelsize 3x3x3), no slice gap and GRAPPA acceleration factor 3, matrix size 72x72, FOV 216x216mm for full brain coverage (TR=2450 ms, TE=28ms, flip angle=75 degrees) using a 64-channel head/neck coil. In addition, Magnetization Prepared Rapid Acquisition Gradient Echo (MPRAGE) images (voxelsize 1x1x1 mm) were acquired using a T1-weighted sequence containing 192 slices in coronal direction, inversion time 900ms, one excitation, GRAPPA acceleration factor 2, matrix size 256 × 256, FOV 256 × 256 mm (TR=2250 ms, TE=2.21 ms, flip angle= 9°).

fMRI data preprocessing
First, raw images were checked for scanner-related artifacts (excluded: 1 n/l-D, 2 m/m-D). Realignment and co-registration were performed using SPM default settings: functional scans were realigned to the mean image using fourth degree of B-spline interpolation, and then coregistered to the individual's anatomical images using the normalized mutual information approach. Data from participants with absolute movement > 4mm were excluded (2 n/l-D, 1 m/m-D). Additionally, imaging time series were examined for excessive motion artifacts using the Artifact Detection Tool (ART) software package (https://www.nitrc.org/projects/artifact_detect). Outlier volumes were identified by assessing scan-to-scan differences (thresholds: global signal=3, composite movement=1). Data from subjects with more than 15% outlier volumes were excluded from further analyses (excluded: 0 n/l-D, 2 m/m-D). Lastly, functional images were normalized to common stereotactic space (Montreal Neurological Institute (MNI) T1-templace) while resampling to 2x2x2 voxelsize after which they were smoothed with a 4mm Gaussian kernel.

Computational model (Q-learning)
A standard Q-learning algorithm was used to calculate the expected value (Q(a,t)) of the performed action (a) at a certain trial (t); and the prediction error (outcome(t)-Q(a,t)) after each action (Sutton and Barto, 1998): $Q(a,t+1) = Q(a,t) + \alpha * (outcome(t) - Q(a,t))$. The model was set to select actions according to a standard softmax logistic function: $P(a_1,t)=[\exp(Q(a_1,t)/\beta)] / [\exp(Q(a_1,t)/\beta) + \exp(Q(a_2,t)/\beta)]$. The two free parameters (α =learning rate, β =temperature) were optimized for every participant to maximize the likelihood of their own trial-by-trial sequence of choices, using the fmincon function in

MATLAB (R2013a). Model fits were compared to a naïve model that assumes participants choose all stimuli with equal probability and had no free parameters (by calculating pseudoR^2 values: $(LLE_{chance} - LLE_{model})/LLE_{chance}$ [1] (McFadden, 1973)).

RPE parameter estimates and ESM measures – models

The following models were analysed (RA=reward anticipation, AP=activity pleasantness, RPE=reward prediction error signal, extracted from Nucleus Accumbens (left and right) and Putamen (left and right), time_overall = time in days (with two decimals) since midnight of the day of the first filled-in beep questionnaire, time_within_day = time in minutes since midnight of that day):

- $Y_{ij} = \alpha_{0i} + \underline{\beta_1 RPE_i} + \beta_2 Age_i + \beta_3 Gender_i\ \beta_4 Education\_level + + \beta_{5i} time\_overall_{ij} + \beta_{6i} time\_within\_day_{ij} + \varepsilon_{ij}$, with Y_{ij} being reward anticipation and activity pleasantness.
- $AP(t)_{ij} = \alpha_{0i} + \beta_{1i} RA(t\text{-}1)_{ij} + \beta_2 RPE_i + \underline{\beta_3 RA(t\text{-}1)_{ij} * RPE_i} + \beta_{4i} AP(t\text{-}1)_{ij} + \beta_5 Age_i + \beta_6 Gender_i + \beta_7 Education\_level + \beta_{8i} time\_overall_{ij} + \beta_{9i} time\_within\_day_{ij} + \varepsilon_{ij}$
- $AP(t)_{ij} = \alpha_{0i} + \beta_{1i} RA(t\text{-}1)_{ij} + \beta_{2i} RA(t\text{-}1)^2_{ij} + \beta_3 RPE_i + \beta_4 RA(t\text{-}1)_{ij} * RPE_i + \underline{\beta_5 RA(t\text{-}1)^2_{ij} * RPE_i} + \beta_{6i} AP(t\text{-}1)_{ij} + \beta_7 Age_i + \beta_8 Gender_i + \beta_9 Education\_level + \beta_{10i} time\_overall_{ij} + \beta_{11i} time\_within\_day_{ij} + \varepsilon_{ij}$

with a random intercept for each participant ($\alpha_{0i} = \alpha + u_{0i}$) and a random slope for all β's of ESM predictors ($\beta_{xi} = \beta_x + u_{xi}$), where $\varepsilon_{ij} \sim N(0, \sigma^2)$, $u_{0i} \sim N(0, \tau_0^2)$ and $u_{xi} \sim N(0, \tau_x^2)$ and covariations between random intercept and random slopes were assumed 0.
The beta's of the underlined model components are reported in Table 2 of the main paper.

ESM beep questionnaire response rates

The 114 participants who provided complete data filled in a total number of 10.001 beep questionnaires (mean=88 beeps per person, sd=31, range=23-165). The 27 participants excluded due to various reasons filled in a total of 2.096 complete beep questionnaires (mean=78 beeps per person, sd=28, range=23-123). The final sample of 87 participants who were analysed filled in a total number of 7.905 complete beep questionnaires (mean: 91 beeps per person, sd=31, range=23-165). On average these 87 participants responded to beep questionnaires on 14.9 days (sd=2.7, range=6-25). The average beep response in the analysed sample was 60% (sd=16%, range=31%-87%). Groups did not differ in average beep response rate (n/l-D: average=60%, m/m-D: average=61%, T=-0.06, *p*=.95).

[1] LLE_{model} corresponds to the maximum logarithmic likelihood of the observed choices under the model. LLE_{chance} corresponds to the logarithmic likelihood of choices at chance [$LLE_{chance} = t*\log(0.5)$], with t being the number of trials.

Supplementary Table 1: *MNI peak coordinates of brain regions encoding Reward Prediction Error in the complete sample (n=87), modelled with fixed group average reward learning rate = 0.2; p < 0.05 Family Wise Error (FWE) cluster corrected, with an initial cluster forming threshold of p = 0.001. Brain region labels according to the Harvard-Oxford Atlas.*

Brain region	**Cluster size**	**MNI (x,y,z)**	**T-score**	**Cluster p (FWE)**
L Supramarginal Gyrus	853	-54, -36, 44	7.72	<.001
L Superior Parietal Lobule		-38, -44, 42	4.94	
L Postcentral Gyrus		-62, -24, 24	3.65	
R Supramarginal Gyrus	616	44, -32, 42	7.20	<.001
R Postcentral Gyrus		60, -16, 32	4.64	
R Superior Parietal Lobule		40, -38, 52	4.20	
L Middle Temporal Gyrus	574	-56, -52, -10	7.20	<.001
L Inferior Temporal Gyrus		-48, -54, -14	5.25	
R Cingulate Gyrus (posterior)	444	4, -32, 42	6.91	<.001
L Cingulate Gyrus (posterior)		-4, -40, 34	4.75	
L Cingulate Gyrus (anterior)	1705	-2, 38, 4	6.83	<.001
L Paracingulate Gyrus		-4, 54, 2	6.82	
R Frontal Pole		2, 56, -2	6.76	
R Cingulate Gyrus (anterior)		2, 38, 10	6.09	
R Paracingulate Gyrus		10, 54, 2	5.46	
R Frontal Medial Cortex		8, 40, -12	5.34	
L Frontal Pole		-8, 58, 8	5.19	
R Putamen	622	18, 8, -10	6.35	<.001
L Accumbens		-12, 10, -8	6.28	
L Putamen		-20, 10,-12	6.20	
R Frontal Orbital Cortex		14, 6, -12	5.86	
R Accumbens		8, 16, -4	5.60	
R Amygdala		22, -2, -16	4.72	
R Inferior Temporal Gyrus	280	58, -48, -14	5.96	<.001
L Frontal Pole	115	-24, 38, -12	5.59	<.001
L Frontal Orbital Cortex		-26, 30, -16	4.79	
R Hippocampus	54	32, -30, -6	5.52	0.022
L Cingulate Gyrus (anterior)	102	-2, 2, 32	5.31	<.001
R Cingulate Gyrus (anterior)		4, -2, 32	4.87	
L Lateral Occipital Cortex	206	-26, -66, 38	5.14	<.001
L Insular Cortex	58	-36, -14, 14	4.86	0.015
L Superior Frontal Gyrus	118	-20, 30, 50	4.67	<.001
L Precuneus Cortex	61	-2, -56, 18	4.66	0.011
L Cingulate Gyrus (posterior)		-4, -52, 24	4.63	
L Inferior Frontal Gyrus	61	-38, 34, 14	4.57	0.011
L Frontal Pole		-44, 40, 14	4.00	
L Hippocampus	72	-26, -28, -10	4.53	0.004
L Precentral Gyrus	49	-50, 2, 34	4.30	0.036

Note. Abbreviations: L=left, R=right.

Supplementary Table 2. *Correlations between mean activity in each ROI*

	R Put	L Put	R NAcc	L NAcc
R Put	1.0000			
L Put	0.5174***	1.0000		
R NAcc	0.5538***	0.2379*	1.0000	
L NAcc	0.6184***	0.3279**	0.6202***	1.0000

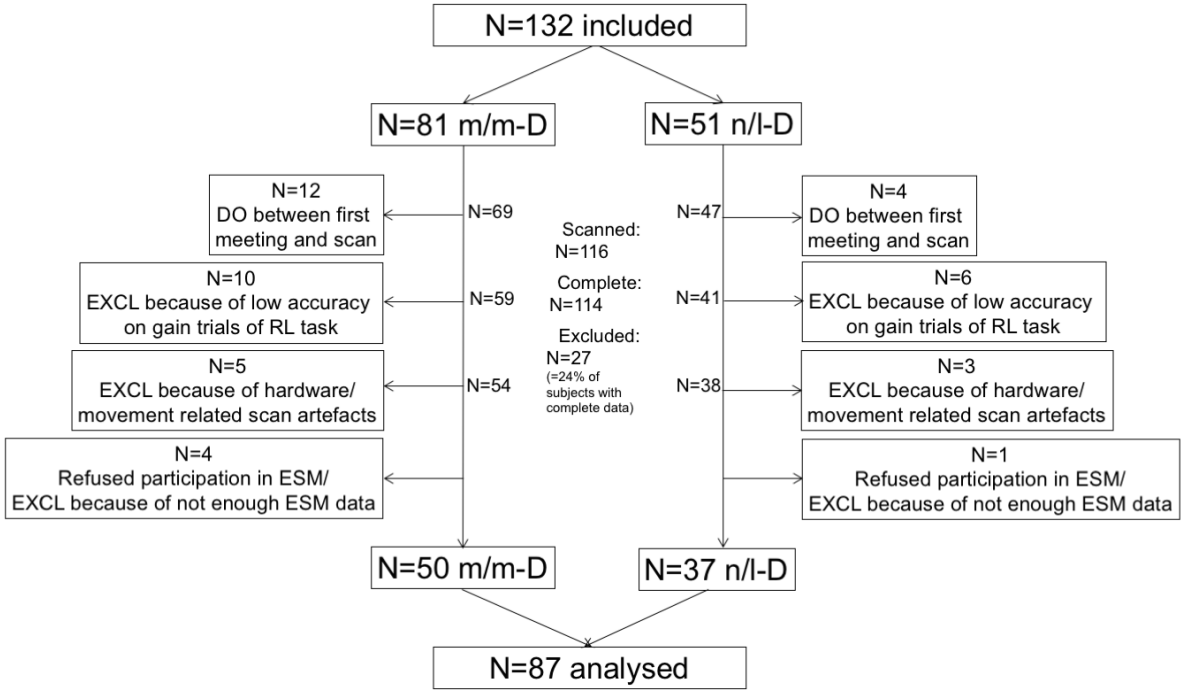
Note. Abbreviations: R=right, L=left, Put=Putamen, NAcc=Nucleus Accumbens, ROI=region of interest.
***<.001, ** <.01, * <.05

Supplementary Table 3. *Mean activation in each ROI (analysed with REX toolbox)*

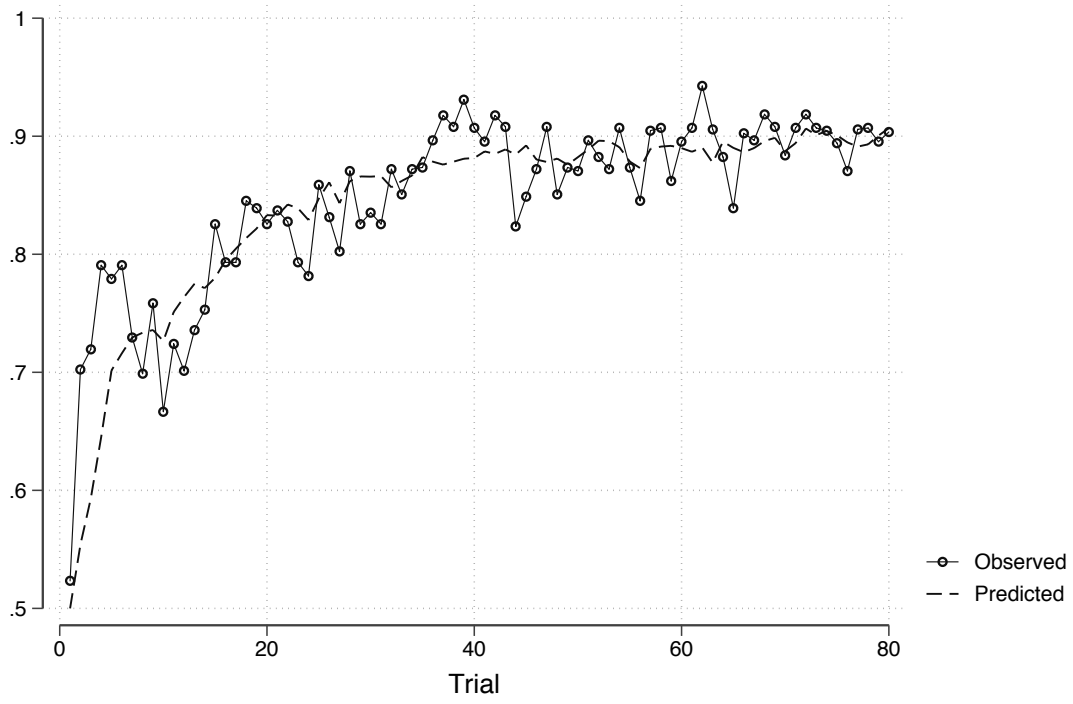
ROI	**beta**	**T**	**ROI p (FDR)**
L NAcc	0.49	7.29	<.001
L Putamen	0.35	6.11	<.001
R NAcc	0.45	6.37	<.001
R Putamen	0.32	5.40	<.001

Note. Abbreviations: R=right, L=left, Put=Putamen, NAcc=Nucleus Accumbens, ROI=region of interest, FDR=False Discovery Rate-corrected.

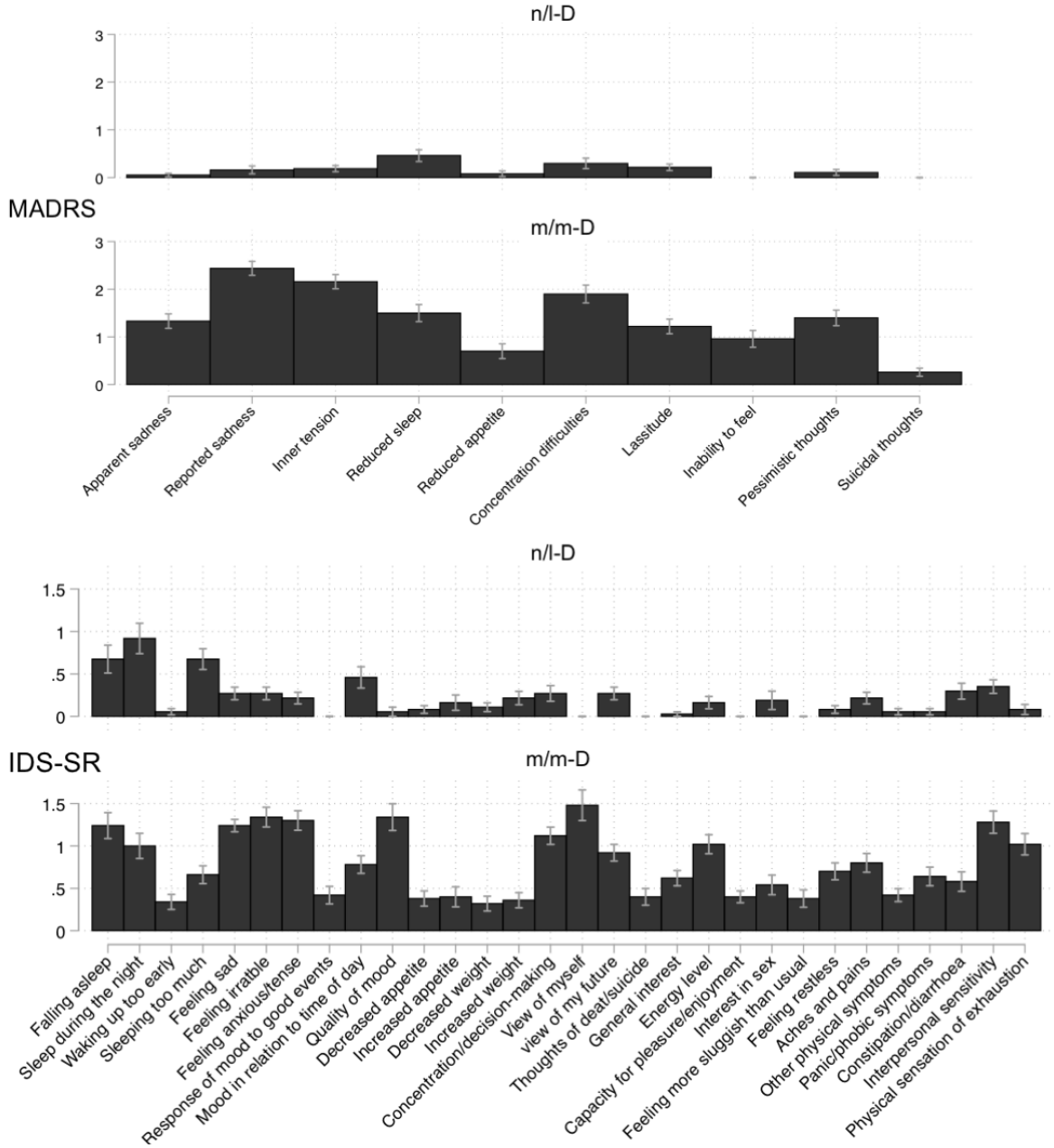
Supplementary Figure 1. *Participant Flow Chart.*
Abbreviations: m/m-D=participants with mild/moderate symptoms of depression; n/l-D =participants with no/low symptoms of depression, DO=drop-out, EXCL=excluded, ESM=Experience Sampling Method,



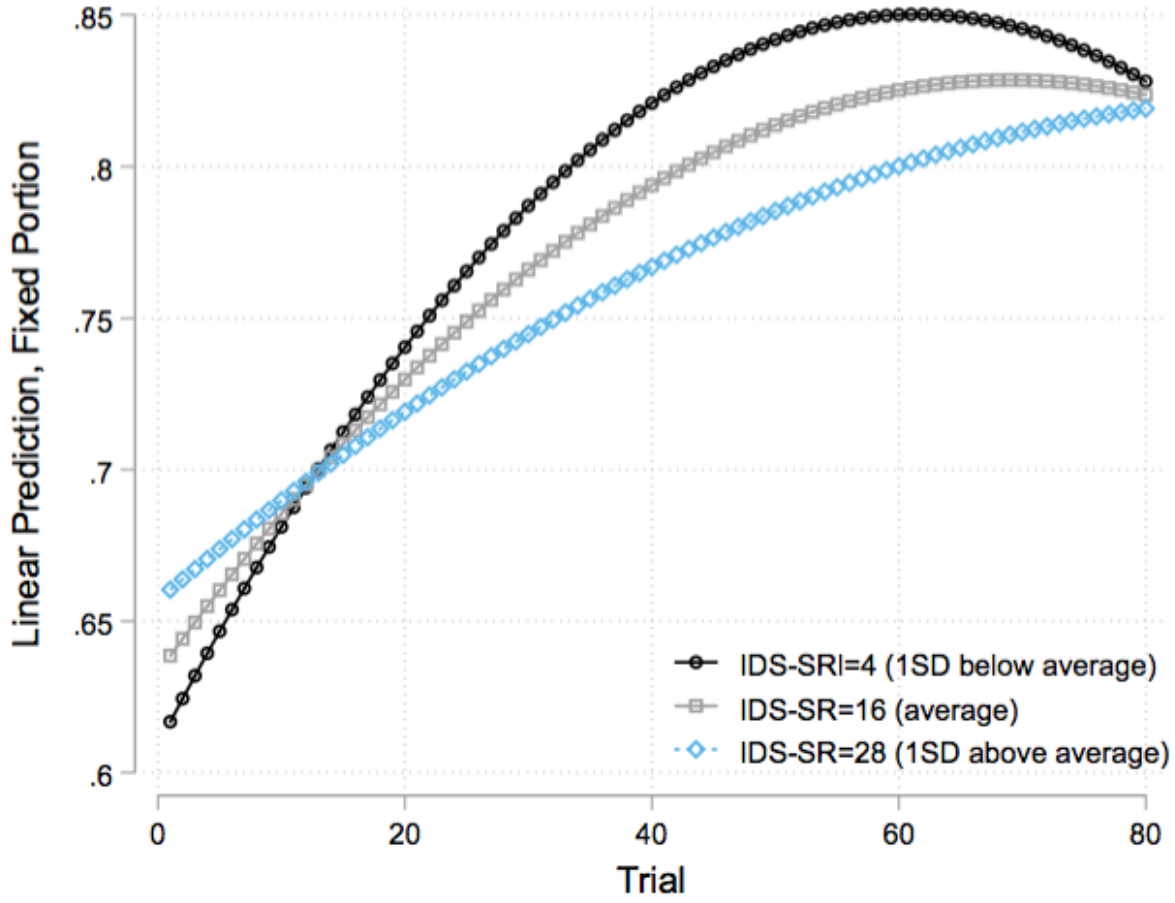
Supplementary Figure 2. *Observed choice accuracy behaviour (average over the whole group) with model predictions overlaid.*



***Supplementary Figure 3**. Group averages per symptom of the IDS-SR and MADRS*



Supplementary Figure 4. *Simple slopes; estimated marginal means for cumulative choice accuracy for average and 1 standard deviation below/above average depression severity.*



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